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Abstract

Dynamic ergometer exercise in a supine position was applied to 64 patients more than 1 year after valvular heart surgery, and the left ventricular reserve was evaluated echocardiographically. The left ventricular reserve declined in the mitral stenosis-mitral valve replacement group, while it was better maintained in the mitral stenosis-mitral commissurotomy, aortic regurgitation and aortic stenosis groups. The patients were divided into 3 groups depending on whether the percentage increase during exercise of stroke index, an index of left ventricular pump function, increased, unchanged, or decreased. The percentage increase of mean velocity of circumferential fibre shortening (y) and that of left ventricular end-diastolic diameter (x) during exercise were plotted for each group. The increased group was isolated from the unchanged group by the line of $y = -5.02x + 30.1$; the unchanged group was isolated from the decreased group by that of $y = -5.68x - 10.0$, and the increased and unchanged groups were clearly isolated from the decreased group by that of $y = -6.86x - 4.76$. We conclude that dynamic ergometer exercise echocardiography is useful for evaluating the left ventricular reserve of postoperative patients with valvular heart disease. It was also thought that the subclinical state of cardiac failure can be effectively detected by the present method.

KEYWORDS: left ventricular reserve, dynamic exercise echocardiography, valvular heart disease, ergometer

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Evaluation of the Left Ventricular Reserve by Dynamic Exercise Echocardiography after Surgery for Valvular Heart Diseases

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Dynamic ergometer exercise in a supine position was applied to 64 patients more than 1 year after valvular heart surgery, and the left ventricular reserve was evaluated echocardiographically. The left ventricular reserve declined in the mitral stenosis-mitral valve replacement group, while it was better maintained in the mitral stenosis-mitral commissurotomy, aortic regurgitation and aortic stenosis groups. The patients were divided into 3 groups depending on whether the percentage increase during exercise of stroke index, an index of left ventricular pump function, increased, unchanged, or decreased. The percentage increase of mean velocity of circumferential fibre shortening (y) and that of left ventricular end-diastolic diameter (x) during exercise were plotted for each group. The increased group was isolated from the unchanged group by the line of $y = -5.02x + 30.1$; the unchanged group was isolated from the decreased group by that of $y = -5.68x - 10.0$, and the increased and unchanged groups were clearly isolated from the decreased group by that of $y = -6.86x - 4.76$. We conclude that dynamic ergometer exercise echocardiography is useful for evaluating the left ventricular reserve of postoperative patients with valvular heart disease. It was also thought that the subclinical state of cardiac failure can be effectively detected by the present method.

Key words : left ventricular reserve, dynamic exercise echocardiography, valvular heart disease, ergometer

Recent advances have made echocardiography useful for evaluating cardiac function (1-5) and this technique is becoming an indispensable non-invasive method for long-term postoperative observation (6-9). The examination of left ventricular function, not only in the resting state but also under exercise,

is important for evaluating the social activity of postoperative patients, because improvement in the quality of life has become a major goal of treatment. Although cardiac catheterization is a reliable method for evaluating left ventricular function, it cannot be easily performed during exercise. Dynamic ergometer exercise is more appropriate for evaluating the daily activity of patients because isometric exercise represents an afterload stress to the left ventricle (10).

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Therefore, in the present study, dynamic ergometer exercise was used to evaluate the left ventricular reserve in patients who had undergone valvular heart surgery.

Subjects and Methods

A total of 74 subjects were included in the present study. Sixty-four cases were operated on during the period from January 1979 to July 1981 at Okayama University Medical School and have been followed up for more than 1 year after the operation. The remaining 10 subjects were healthy. The 64 patients included 31 with mitral stenosis (MS), 6 with mitral steno-regurgitation (MSR), 13 with mitral regurgitation (MR), 9 with aortic regurgitation (AR), and 5 with aortic stenosis (AS). Mitral commissurotomy was performed in 17 cases (MS-MC) and valve replacement (MS-MVR) in 14 out of the 31 MS cases. Out of the 17 MS-MC cases, open mitral commissurotomy was performed in 14 cases, and closed mitral commissurotomy in 3. Three cases among the 9 AR cases, and 2 among the 5 AS cases were complicated with MS, and open mitral commissurotomy was applied to all of these cases. MVR was performed in all cases of MSR or MR, and AVR was performed in all cases of AS or AR. In the MS-MC group the valve area, which was $0.8\text{--}2.0\text{ cm}^2$ ($1.3 \pm 0.3\text{ cm}^2$) preoperatively, was enlarged to $2.4\text{--}3.0\text{ cm}^2$ ($2.6 \pm 0.2\text{ cm}^2$) postoperatively. Björk-Shiley valves were used mostly for the mitral valve. A Hancock valve, Carpentier-Edwards valve and Ionescu-Shiley valve were used in one case each. Lillehei-Kaster valves and Omni-Science valves were used for the aortic valve. Surgery was carried out, in principle, at mild hypothermia and under cardiac arrest, using topical cooling

and cold cardioplegia.

As shown in Table 1, there was no significant difference among groups as to the age at surgery. The bypass time was significantly shorter, 66.7 ± 25.9 min, in the MS-MC group than in the other groups, but no significant difference was observed among the groups which were treated with valve replacement.

A Toshiba SSH-11A ultrasonoscope with a 2.4-MHz transducer (Toshiba Corp., Tokyo, Japan) was used for the dynamic exercise echocardiography. M-Mode echocardiograms were recorded using a strip chart recorder (Honeywell Inc., Denver, CO, USA) at a 50 mm/sec paper speed. The patient was in a supine position, and the transducer was placed onto either the III or the IV intercostal space of the left sternal edge where the characteristic echo from the anterior cusp of the mitral valve could be identified. The transducer was then angled to demonstrate the interventricular septum and the left ventricular posterior wall just below the tip of the mitral leaflets at the level of chordae tendineae.

An ergometer (Monak, Varberg, Sweden) was used for dynamic exercise. Three minute loading at 25 watts and 3 min loading at 50 watts, a total of 6 min, was applied with the patient in the supine position. M-Mode echocardiogram recordings were made immediately after the loading, mainly during expiration. Out of 64 cases with valvular disease, 50 cases could be tested with ergometer exercise. Fourteen cases were excluded because of complications with paralysis of the lower extremities due to thrombosis or tachycardia at rest. The appearance of anginal pain and ST depression in ECG at $>2\text{ mV}$ were not observed during exercise in any of the cases. The left ventricular function of 64 cases was graded according to the New York Heart Association (NYHA) clas-

Table 1 Clinical and surgical data

	MS		MSR	MR	AR	AS
	MC	MVR				
No. of cases	17	14	6	13	9	5
Age (year)	42.7 ± 9.3	44.4 ± 8.8	49.3 ± 3.3	43.3 ± 12.7	32.3 ± 7.7	43.4 ± 3.1
Bypass time (min)	66.7 ± 25.9	122.2 ± 17.6	113.8 ± 30.1	116.7 ± 30.1	114.4 ± 21.2	120.2 ± 7.5

Abbreviations: MS, mitral stenosis; MSR, mitral steno-regurgitation; MR, mitral regurgitation; AR, aortic regurgitation; AS, aortic stenosis; MC, mitral commissurotomy; MVR, mitral valve replacement.

sification, and 52 cases were classified as Grade I (NYHA-I group), and 12 cases were classified as Grade II (NYHA-II group). Ergometer exercise could be performed on 44 out of the 52 NYHA-I cases and 6 out of the 12 NYHA-II cases. Changes in the left ventricular function due to exercise were examined in terms of the heart rate (HR), stroke index (SI), cardiac index (CI), left ventricular end-diastolic diameter (Dd) and mean velocity of circumferential fibre shortening (mVcf). In the patients with atrial fibrillation, these measurements were taken on 10 beats that closely approximated the average HR interval for the basal ventricular response. The value of mVcf was calculated by $Dd - Ds / Dd \times ET$, where Ds is the left ventricular end-systolic diameter and ET is the ejection time. The left ventricular volume was estimated by Teichholtz's equation (4). Ten normal subjects without heart disease were used as the control (normal) group for the purpose of comparison.

For the evaluation of the left ventricular reserve, SI and CI were used as indexes of the left ventricular pump function, mVcf as an index of the myocardial contractility, and Dd as an index of the preload. Changes in each index due to exercise were expressed as the percent change (% Δ) from the resting value.

The subjects were divided into 3 groups according to the magnitude of exercise-induced changes in the left ventricular pump function using SI as an index. The increased group was defined as that showing more than a 10% increase in % Δ SI. The unchanged group was defined as that exhibiting a change in % Δ SI from -10% to +10%. The decreased group was defined as that showing more than a 10% decrease in % Δ SI. The value of % Δ SI was calculated by the equation $\% \Delta SI = (SI_{ex} - SI_r) \times 100\% / SI_r$, where "ex" and "r" represent exercise and rest, respectively. The left ventricular reserve was evaluated in terms of mVcf, which reflects the myocardial contractility, and Dd, which represents the preload.

All data were analyzed with Student's *t*-test, using either paired or unpaired data, with $P < 0.05$ being considered significant. All values were stated as the mean \pm the standard deviation.

Results

Left ventricular function based on the NYHA classification. In the resting state there was no significant difference in HR, SI, CI, Dd or mVcf between the normal group

Table 2 Hemodynamic parameters obtained by dynamic ergometer exercise echocardiography in normal subjects and NYHA I and NYHA II patients

Subjects	Condition (No. of cases)	HR/min	SI (ml/m ²)	CI (l/min/m ²)	Dd (cm)	mVcf (circ/sec)
Normal	R (10)	71.4 \pm 12.5	40.3 \pm 9.3	2.76 \pm 0.45	4.65 \pm 0.44	1.36 \pm 0.23
	E (10)	97.1 \pm 14.3	46.0 \pm 9.6	4.38 \pm 0.81	4.65 \pm 0.43	1.91 \pm 0.30*
NYHA I	R (52)	73.0 \pm 9.8	40.6 \pm 9.3	2.89 \pm 0.66	4.60 \pm 0.51	1.18 \pm 0.24
	E (6)	96.3 \pm 14.3*	41.4 \pm 10.4	3.94 \pm 1.03*	4.53 \pm 0.51	1.51 \pm 0.43*
NYHA 2	R (12)	76.9 \pm 29.0	42.2 \pm 8.3	3.03 \pm 0.62	4.86 \pm 0.50	1.03 \pm 0.25
	E (6)	85.4 \pm 14.5	36.7 \pm 10.4	3.03 \pm 0.78	4.74 \pm 0.58	1.01 \pm 0.33

Abbreviations: HR, heart rate; SI, stroke index; CI, cardiac index; Dd, left ventricular end-diastolic diameter; mVcf, mean velocity of circumferential fibre shortening; NYHA I and II, Grades I and II of New York Heart Association classification; R, rest; E, exercise; *, significantly different from R ($p < 0.01$).

and the NYHA-I or II group. Ergometer exercise increased HR, CI and mVcf significantly ($p < 0.01$), but SI was raised only slightly. In the NYHA-II group, on the other

hand, HR greatly increased, while mVcf and SI showed a tendency to decrease. In all 3 groups, Dd was little affected by exercise loading (Table 2, Figs. 1 and 2).

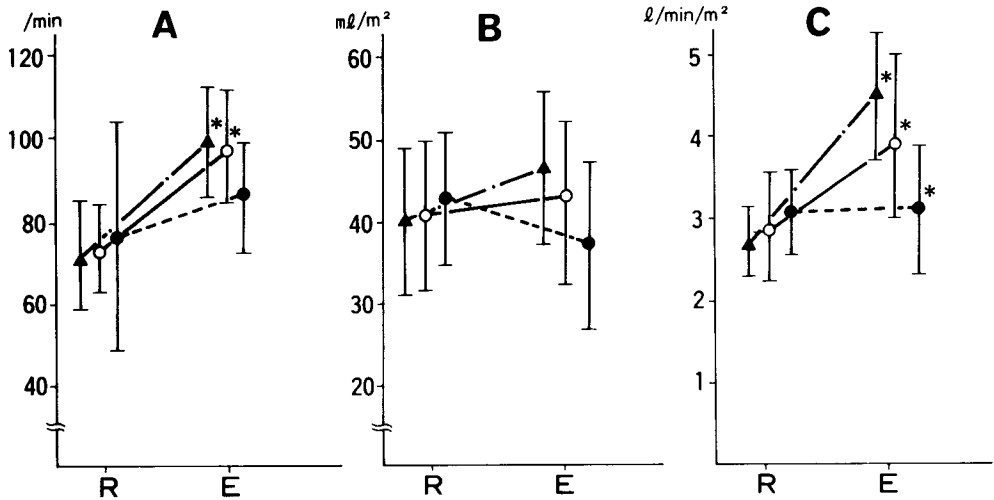


Fig. 1 Effect of 6 min of ergometer exercise (E) on heart rate (A), stroke index (B) and cardiac index (C) in normal subjects (▲—▲) and Grades I (○---○) and II (●.....●) patients of New York Heart Association classification. *, Significantly different from R (rest), $p < 0.01$.

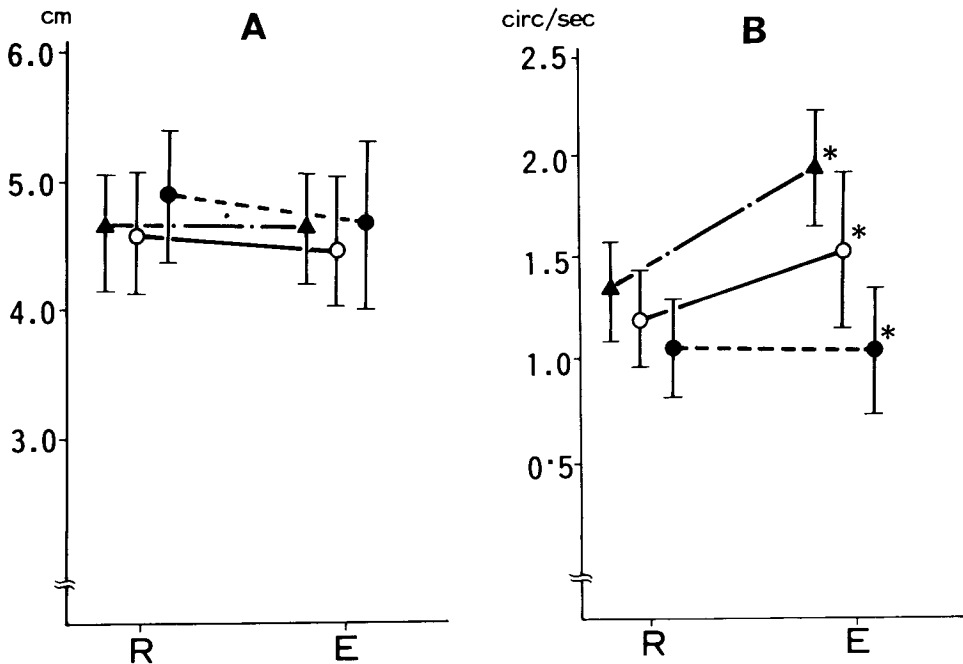


Fig. 2 Effect of 6 min of ergometer exercise (E) on left ventricular end-diastolic dimension (A) and mean velocity of circumferential fibre shortening (B) in normal subjects (▲—▲) and Grades I (○---○) and II (●.....●) patients of New York Heart Association classification. *, Significantly different from R (rest), $p < 0.01$.

Table 3 The left ventricular reserve with respect to the percent change in the stroke index (% Δ SI) determined by ergometer exercise echocardiography^a

% Δ SI	No. of cases						
	Normal	MS-MC	MS-MVR	MSR	MR	AR	AS
% Δ SI $\geq 10\%$	5	7	1	0	0	5	2
$-10\% < \Delta$ SI $< 10\%$	5	3 (1)	4 (2)	2	5	2	1
% Δ SI $\leq -10\%$	0	4	6 (2)	2	5 (1)	1	0
Total	10	14 (1)	11 (4)	4	10 (1)	8	0
							60 (6)

a: See footnotes to Tables 1 and 2.

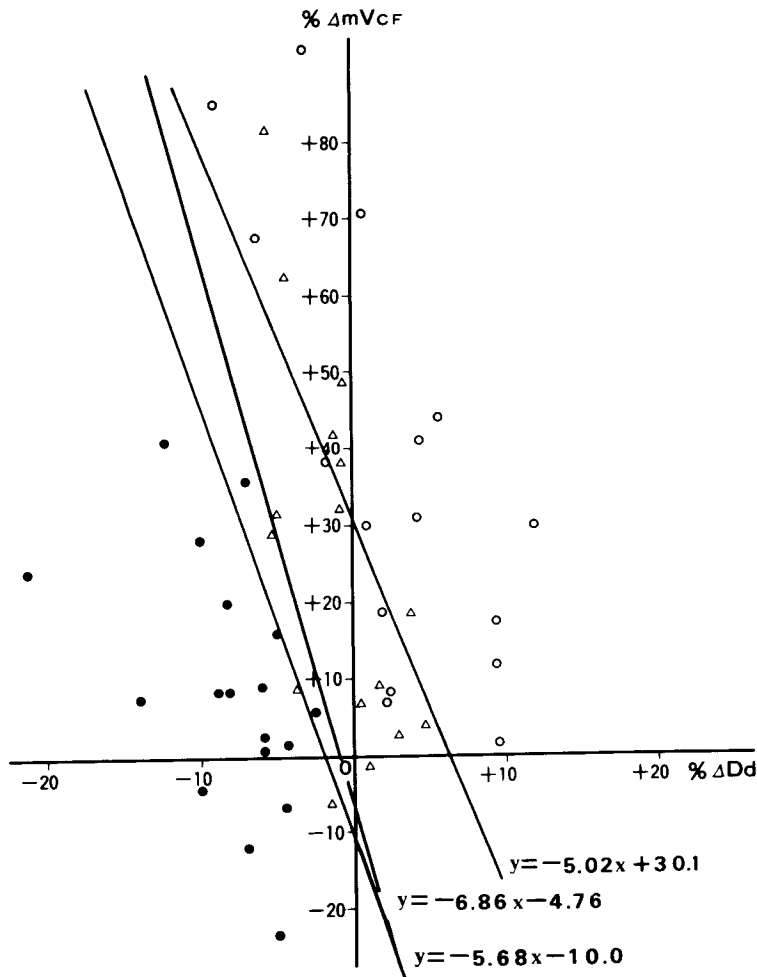


Fig. 3 Correlation between percent change in mean velocity of circumferential fibre shortening (% Δ mVcF, y) and percent change in left ventricular end-diastolic diameter (% Δ Dd, x). Patient groups were divided according to percent change of stroke index (% Δ SI): ○, % Δ SI $\geq 10\%$; △, $-10\% < \Delta$ SI $< 10\%$; ●, Δ SI $\leq -10\%$. The increased and unchanged groups were discriminated by $y = -5.02x + 30.1$, and the unchanged and decreased groups by $y = -5.68x - 10.0$. The increased and unchanged groups were clearly discriminated from the decreased group by $y = -6.86x - 4.76$.

Left ventricular reserve based on the type of operation. Among the 10 normal subjects, 5 were in the increased group, and the other 5 were in the unchanged group. There was no subject in the decreased group. On the other hand, 6 out of 11 MS-MVR cases, 2 out of 4 MSR cases and 5 out of 10 MR cases were found in the decreased group. In the AR group, only 1 case out of 8 was in the decreased group, while no case was in this group in the AS group. In the MS-MC group, 7 out of 14 cases belonged to the increased group, 3 cases to the unchanged group, and 4 cases to the decreased group, indicating a larger variation than in the other groups. Among the NYHA-II cases, 3 were in the unchanged group and 3 were in the decreased group, but no case belonged to the increased group (Table 3).

Correlation between myocardial contractility reserve function, preload reserve function and pump reserve function. The values of $\% \Delta mVcf$ and $\% \Delta Dd$ under exercise loading were plotted on the ordinate and abscissa, respectively, for each of the 3 groups classified according to $\% \Delta SI$ values. As shown in Fig. 3, the increased, unchanged, and decreased groups showed relatively distinctive distributions. Discriminating analysis of these 3 groups yielded the following linear equations. The increased and unchanged groups were discriminated by $y = -5.02x + 30.1$, and the unchanged and decreased groups were discriminated by $y = -5.68x - 10.0$. The increased and unchanged groups were clearly discriminated from the decreased group by $y = -6.86x - 4.76$.

Discussion

The social activity of patients long after cardiac surgery has increasingly been considered in recent follow-up studies (11-15). Although the measurement of angiographic

ventricular volume and other parameters derived from it have given valuable information about left ventricular performance, cardiac catheterization and angiography are not without risk and cannot be performed repeatedly to assess the progression of myocardial dysfunction. Recently, echocardiography has been used to study left ventricular performance because it can be applied non-invasively and repeatedly. Some investigators have measured the left ventricular function under exercise loading using echocardiography (7, 16, 17). Isometric exercise produces a relatively greater increase in blood pressure that may result in sufficient afterload stress to account for the decrease in left ventricular performance (10). We, therefore, evaluated the left ventricular reserve by dynamic ergometer exercise echocardiography, which results in less afterload stress compared with isometric exercise and is more appropriate for evaluating the daily activities of patients. Patients who have severe mitral valvular disease or elevated pulmonary vascular resistance were most unlikely to tolerate maximum exercise loading and it was not necessary for these patients.

The pump function is most important for evaluating the left ventricular function because it represents the total activity of cardiac function. Unless the left ventricular function deteriorates below a certain threshold, or the compensatory mechanism based on various factors becomes abnormal, the values of SI and CI, indexes of the left ventricular pump function, do not easily become abnormal (18). We examined the left ventricular reserve of patients after valvular heart surgery using SI and CI as the final indexes of the left ventricular pump function, Dd as an index of the preload and mVcf as an index of the myocardial contractility.

As regards the relation between the val-

ues of SI and CI and the NYHA classification, Kinoshita (19), reported that SI and CI values for NYHA-I and II groups were not different from those for healthy subjects, and constant levels were maintained under compensatory mechanisms. Also in our study, the SI and CI values at rest in the NYHA-I and II groups differed little from those of normal subjects. Under exercise loading, however, the NYHA-I group showed increases in SI and CI, while the NYHA-II group exhibited a marked decrease in SI, suggesting the dysfunction of compensatory mechanisms. Thus, depression of the left ventricular reserve in the NYHA-II group was suspected.

Dd, an index of the preload, may be thought to represent one of the compensatory mechanisms under the depressed cardiac state rather than to be an index of the left ventricular pump function (19, 20). Thus, a good correlation to NYHA classifications cannot be expected. In fact, the Dd value was little affected by exercise loading in the present study.

It is said that depression of the myocardial contractility induces a parallel decrease in the preload reserve, and when such decreases in the preload reserve reach a limit, a decrease in mVcf occurs, while with increases in the afterload, more decreases in mVcf are induced. Therefore, mVcf is thought of as an index which reflects responses to both the preload and afterload. In the present study, the NYHA-I group under exercise loading showed a marked increase in mVcf in a similar manner to the normal group, while the NYHA-II group exhibited a decrease in mVcf, thus being suggestive of depressed myocardial contractility and reduced left ventricular reserve. The percentage increase of SI ($\% \Delta SI$) induced by exercise loading is thought to be increased or unchanged when there is sufficient left ventricular reserve, but to be decreased gradually as the left ventricular reserve

declines. Among our cases, $\% \Delta SI$ was increased in 5 cases, unchanged in 5 cases and decreased in no case in the normal group. In the AR and AS groups, there was only 1 case with decreased $\% \Delta SI$, while more than half of the cases in the MS-MVR, MSR or MR group were found to belong to the decreased group. The MS-MC group on the other hand showed variation in the left ventricular reserve. There was a great number of better cases than other groups with mitral valve replacement. These findings indicate that sufficient left ventricular reserve was maintained in the AR and AS groups, while postoperative depression of the left ventricular reserve was obvious in the MS-MVR, MSR or MR group.

When the values of $\% \Delta mVcf$ and $\% \Delta Dd$ were plotted, 3 groups with increased, unchanged and decreased $\% \Delta SI$ showed different distributions, namely from the upper right toward the lower left, indicating mutual relations among these groups. Thus, maintenance of SI was attempted by using either $\% \Delta mVcf$ or $\% \Delta Dd$, depending upon individual cases, but the value of $\% \Delta Dd$ was mostly within a range from -10% to $+10\%$. Therefore, $\% \Delta mVcf$ is thought to be primarily concerned with the maintenance of SI within a compensable range.

Various causes for continued suboptimal left ventricular contractility secondary to open heart surgery have been cited: rheumatic myocarditis (21, 22), excessive afterload associated with depressed myocardial fibers (23), myocardial ischemic damage (24), and recurrent coronary micro embolism (25).

In rheumatic mitral valvular disease, specific myocardial changes have been well documented in which rheumatic myocarditis is associated with chronic arteriolitis and perivascular fibrosis (26). Atrial fibrillation seen in most of the severe mitral valvular patients contributes to depression of cardiac output and myocardial contractility.

Myocardial fibrosis in rheumatic valvular heart disease may occur as a result of direct injury from the immune response in rheumatic myocarditis or of ischemic injury secondary to intraluminal narrowing of the coronary arterioles (27, 28). Intra-myocardial fibrosis also occurs from ischemic necrosis in the myocardium during cardiac surgery. The degree of fibrosis might correlate with the myocardial reserve function.

Further investigation is recommended to evaluate the preoperative left ventricular reserve. Postoperative improvement of cardiac function could be predicted beforehand by using dynamic exercise echocardiography.

We conclude that dynamic exercise echocardiography is useful for the evaluation of the left ventricular reserve in patients who have undergone valvular heart surgery and for the detection of the subclinical state of cardiac failure.

References

1. Pombo JF, Troy BL and Russel RO Jr: Left ventricular volumes and ejection fraction by echocardiography. *Circulation* (1971) **43**, 480-490.
2. Gibson DG: Estimation of left ventricular size by echocardiography. *Br Heart J* (1973) **35**, 128-134.
3. Feigenbaum H, Popp RL, Wolfe SB, Troy BL, Pombo JF, Haine CL and Dodge HT: Ultrasound measurements of the left ventricle. A correlative study with angiography. *Arch Intern Med* (1972) **129**, 461-467.
4. Teichholtz LE, Kreulen T, Herman MV and Gorlin R: Problems in echocardiographic volume determinations: Echocardiographic-angiographic correlations in the presence or absence of asynergy. *Am J Cardiol* (1976) **37**, 7-11.
5. Kronik G, Slany J and Mossbacher H: Comparative value of eight echocardiographic formulas for determining left ventricular stroke volume. A correlative study with thermodilution and left ventricular single-plane cineangiography. *Circulation* (1979) **60**, 1308-1316.
6. Clark RD, Korcusba K and Cohn K: Serial echocardiographic evaluation of left ventricular function in valvular disease, including reproducibility guidelines for serial studies. *Circulation* (1980) **62**, 564-575.
7. Sano S: Echocardiographic evaluation of the serial changes in cardiac functions before and after surgery of valvular heart diseases and the left ventricular reserve by the dynamic exercise. *Jpn J Thorac Surg Soc* (1983) **31**, 73-85.
8. Gaasch WH, Andrias CW and Levine HJ: Chronic aortic regurgitation: The effect of aortic valve replacement on left ventricular volume, mass and function. *Circulation* (1978) **58**, 825-836.
9. Burggraf GW and Craige E: Echocardiographic studies of left ventricular wall motion and dimensions after valvular heart surgery. *Am J Cardiol* (1975) **35**, 473-480.
10. Crawford MH, White DH and Amon KW: Echocardiographic evaluation of left ventricular size and performance during handgrip and supine and upright bicycle exercise. *Circulation* (1979) **59**, 1188-1196.
11. Peter CA, Austin EH and Jones RH: Effect of valve replacement for chronic mitral insufficiency on left ventricular function during rest and exercise. *J Thorac Cardiovasc Surg* (1981) **82**, 127-135.
12. Borer JS, Rosing DR, Kent KH, Bacharach SL, Green MV, McIntosh CJ, Morrow AG and Epstein SE: Left ventricular function at rest and during exercise after aortic valve replacement in patients with aortic regurgitation. *Am J Cardiol* (1979) **44**, 1297-1305.
13. Bisset AS, Meyer RA, Hirschfeld S, James FW, Schwartz DC and Kaplan S: Aortic valve replacement in childhood: Evaluation of left ventricular function by electrocardiography and graded exercise testing. *Am J Cardiol* (1983) **52**, 568-572.
14. Newman GE, Rerych SK, Bounous PE, Upton MT and Jones RH: Non-invasive assessment of hemodynamic effects of mitral valve commissurotomy during rest and exercise in patients with mitral stenosis. *J Thorac Cardiovasc Surg* (1979) **78**, 750-756.
15. Hossack KF, Bruce RA, Ivey TD, Kusumi FI and Kannagi T: Improvement in aerobic and hemodynamic responses to exercise following aorto-coronary bypass grafting. *J Thorac Cardiovasc Surg* (1984) **87**, 901-907.
16. Sugishita Y and Koseki S: Dynamic exercise echocardiography. *Circulation* (1979) **60**, 743-752.
17. Sugishita Y, Koseki S and Matsuda M: Evaluation of left ventricular reserve by dynamic exercise echocardiography. *J Cardiology* (1980) **10**, 689-696.
18. Mason DT: Congestive Heart Failure. Yorke Medical Books, New York (1976) pp 111-128.
19. Kinoshita M: Studies on cardiac output to blood volume and renal circulation in chronic congestive heart failure. *Jpn Circ J* (1968) **32**, 249-270.
20. Vatner SF and Pagani M: Cardiovascular adjustments to exercise: Haemodynamics and mechanisms. *Prog Cardiovasc Dis* (1976) **19**, 91-108.
21. Harvey RM, Ferrer MI, Samet P, Bader RA, Bder ME, Cournand A and Richards DW: Mechanical and

- myocardial factors in rheumatic heart disease with mitral stenosis. *Circulation* (1955) **11**, 531-551.
22. Fleming HA and Wood P: The myocardial factor in mitral valve disease. *Br Heart J* (1959) **21**, 117-122.
 23. Mantle JA, Hood WP Jr, Kouchoukos NT, Karp RB, Zisserman D and Rackley CE: Physiologic basis for afterload reduction following mitral valve replacement (abst). *Am J Cardiol* (1978) **41**, 420.
 24. Hildner FJ, Javier RP, Cohen LS, Samet P, Nathan MJ, Yahr WZ and Greenberg JJ: Myocardial dysfunction associated with valvular heart disease. *Am J Cardiol* (1972) **30**, 319-326.
 25. Maloney JV Jr, Cooper N, Mulder DG and Buckberg GD: Depressed cardiac performance after mitral valve replacement. A problem of myocardial preservation during operation. *Circulation* (1975) **51** (Suppl 1) 3-7.
 26. Grisner JT, Anderson WR and Weiss L: Chronic occlusive rheumatic coronary vasculitis and myocardial dysfunction. *Am J Cardiol* (1967) **20**, 739-745.
 27. Kennedy JW, Doces J and Stewart DK: Left ventricular function before and following aortic valve replacement. *Circulation* (1977) **56**, 944-950.
 28. Sunamori M, Suzuki A and Harrison GE: Relationship between left ventricular morphology and postoperative cardiac function following valve replacement for mitral stenosis. *J Thorac Cardiovasc Surg* (1983) **85**, 727-732.

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